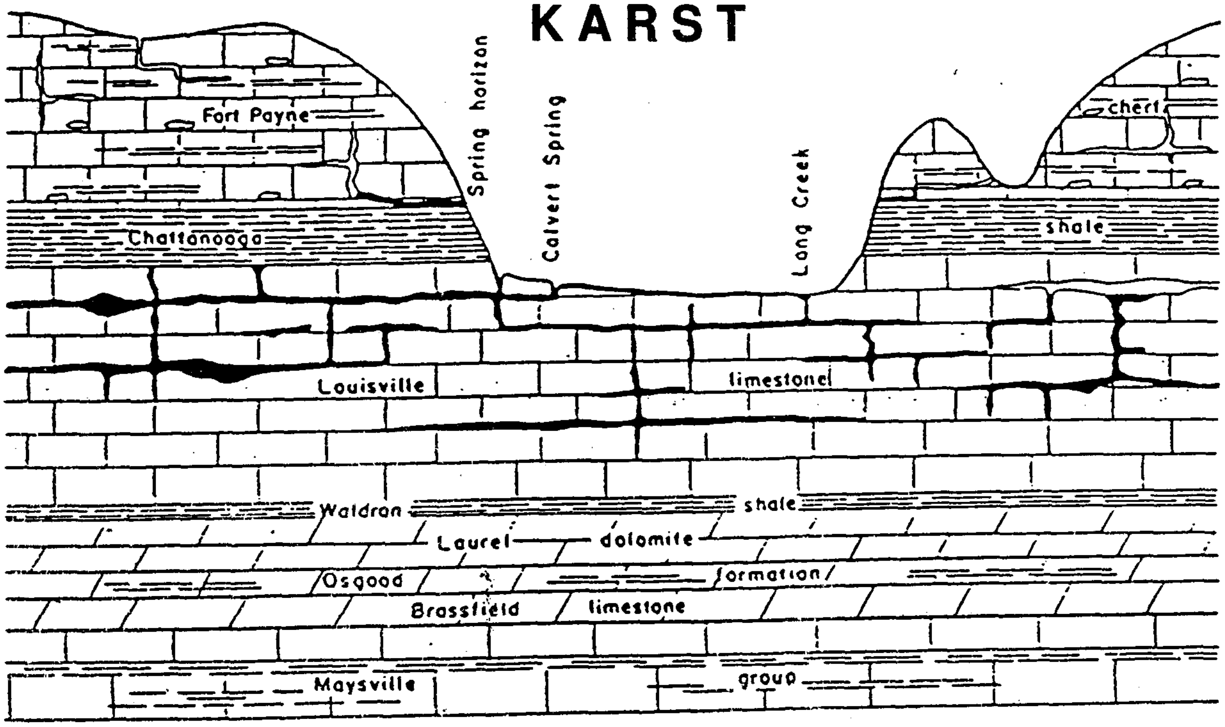
GROUNDWATER AND KARST



Natural Resources and Environmental Protection Cabinet

Department for Environmental Protection

Division of Water

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THE HYDROLOGIC CYCLE

All of the water in the oceans, the atmosphere, and on and in the land is part of a natural system called the hydrologic cycle. The system is truly cyclical because the same water moves through the ocean, atmosphere, and land time and time again. Groundwater is an important component of this water circulatory system. Water-bearing formations of the earth's crust both transmit and act as reservoirs for storage of water. Water enters these formations and generally travels slowly for varying distances, until it returns to the earth's surface.

Figure 1 illustrates the hydrologic cycle. This ongoing system is powered by solar energy. The sun's heat causes water to evaporate from the surface of the ocean and other bodies of water. Water also evaporates from surface materials and the soil. Water vapor accumulates in the air and forms clouds as it cools. When clouds cool further, precipitation falls as rain, sleet, hail, or snow. Some of the precipitation evaporates into the upper atmosphere before it reaches the land surface.

Transpiration also contributes water vapor to the atmosphere. An amazing amount of water is released from plants through this process. For example, one birch tree can release 70 gallons of water per day while an acre of corn gives off 4000 gallons of water per day.

Another source of water vapor is sublimation. This process occurs when ice and snow change form directly from a solid state to water vapor without first being converted to a liquid.

Rainwater falling on the earth's surface either infiltrates the soil or drains off as surface water. Water infiltrating the soil accumulates as soil moisture to be used by plants, and percolates downward through pore spaces in the soil and rock material. Downward-infiltrating surface water moves through the soil moisture zone into the unsaturated zone (Figure 2) in which the pore spaces are partially air-filled. Water then continues downward into the saturated zone. Here the pore spaces are entirely water-filled, and the water within is called groundwater. Groundwater moves down-gradient as it migrates toward the oceans. In places it reappears at the land surface as springs. It may discharge into lakes or surface streams, contributing a base flow that keeps the streams flowing in dry weather.

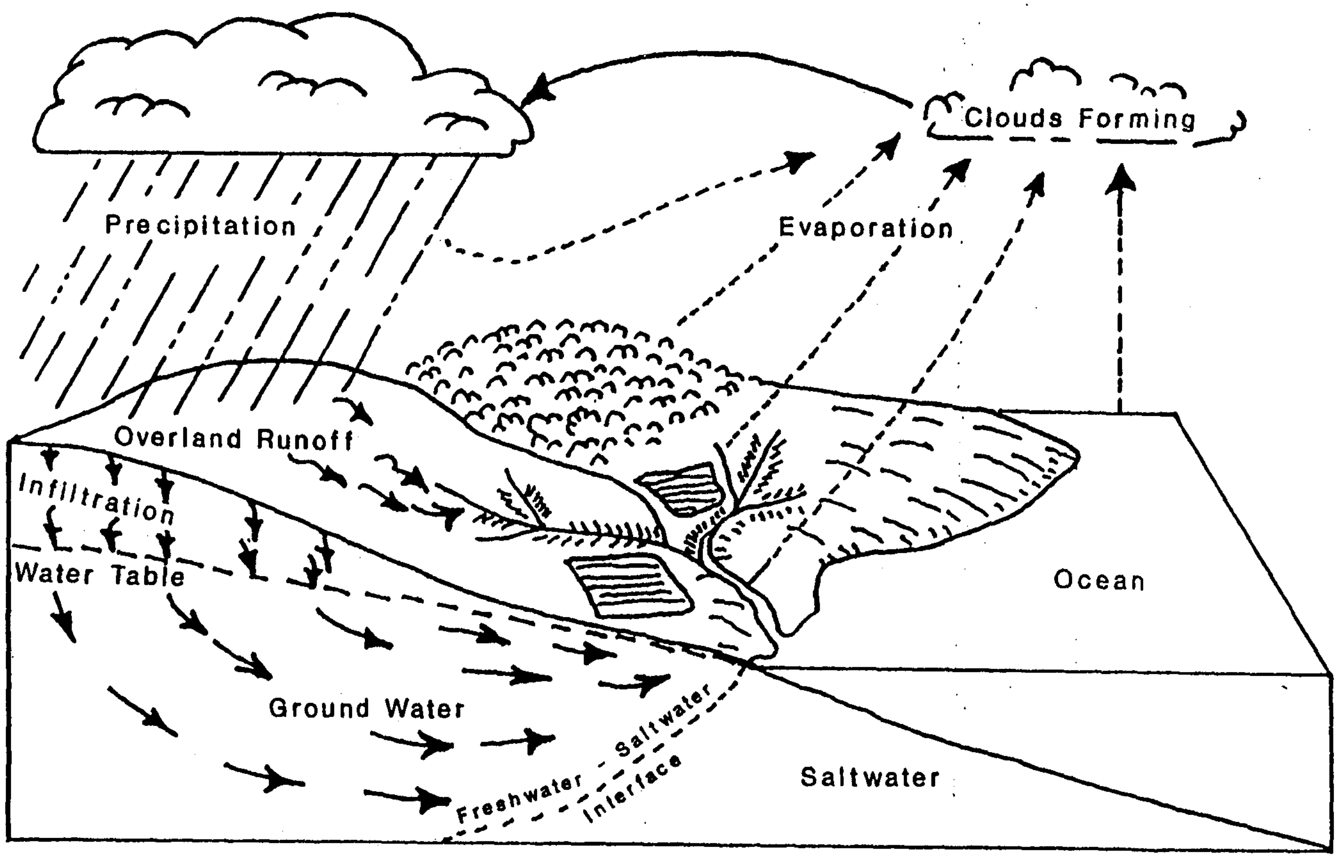

Figure 1. The Hydrologic Cycle (Heath, 1982).

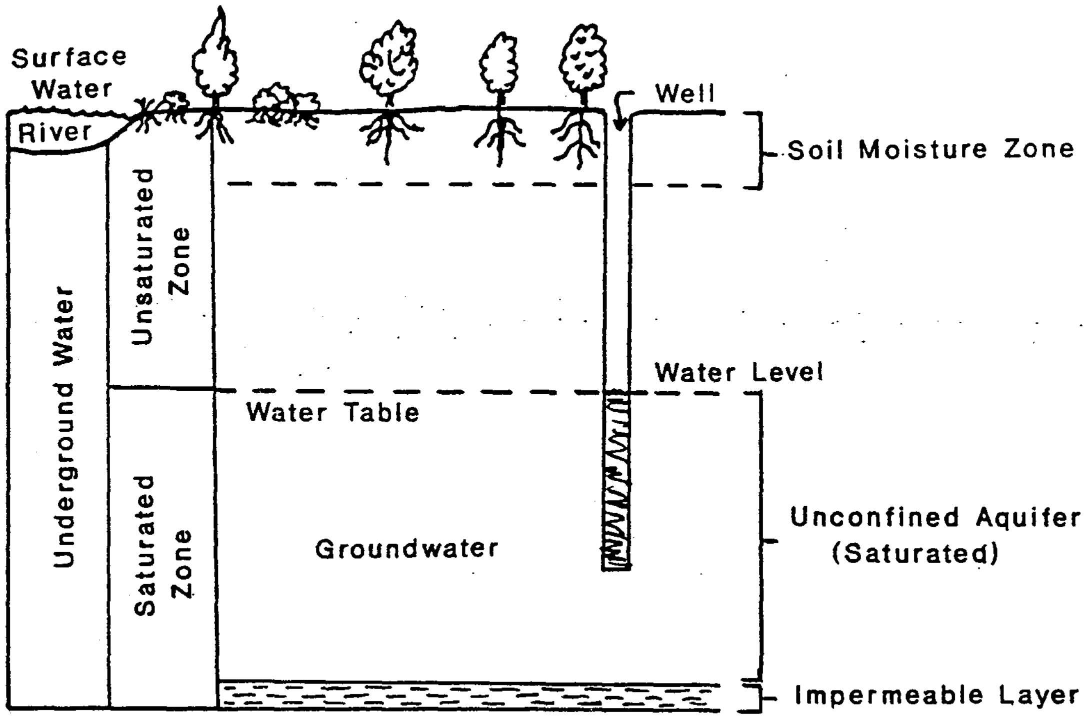

Figure 2. Vertical Distribution of Underground Water in a Typical Unconfined Aquifer (modified after Heath, 1982).

MOVEMENT OF GROUNDWATER

The storage and movement of groundwater is related to porosity and permeability of the rock or sediment.

Porosity

The amount of groundwater that can be contained in rock or sediment depends upon its porosity. Porosity is the percentage of the total volume of rock or sediment that consists of pore spaces (voids, interstices). There are two types of porosity, primary and secondary.

Primary porosity is the original pore space between the particles or grains of the rock. It is created by the geologic processes governing deposition of the sediment and forms before the sediment is lithified. Sediments can be deposited by water, wind, ice, or gravity. Each of these processes has different effects upon sediment particles. Understandably, variations in primary porosity can be great. Generally, sediment is quite porous, the amount of open spaces ranging from 10 to 50 percent of the sediment's total volume.

The amount of pore space depends upon the size and shape of the sediment particles, as well as the compactness of their arrangement (packing). Sorting of the grains according to size and shape also affects porosity, as does the degree of cementation. Porosity is reduced in sediments composed of particles of mixed sizes, because the finer particles tend to fill in the voids between the larger particles (Figure 3B). Infilling by cement (calcite, silica, clay) may either eliminate or reduce pore space (Figure 3D). Rocks having crystalline texture such as limestone have little or no primary porosity because the individual grains interlock. In limestones, primary porosity usually ranges from less than 1 to 30 percent. The individual grains interlock or are cemented by calcite, resulting in little or no free pore space. Hence, limestone could be considered an insignificant reservoir for groundwater. However, where secondary porosity is present significant quantities of groundwater may be available.

Secondary Porosity forms after the sediment has lithified. This type of porosity is most commonly the result of fracturing of the rock mass. Secondary porosity is provided by fractures, joints, cracks, bedding-plane partings, and solution-enlarged conduits (Figure 3, E and F). Secondary porosity is the predominant type of porosity in limestone, shale, siltstone, and tightly cemented sandstone. In limestone, most groundwater storage and movement occurs in solution-enlarged conduits and fractures.

Porosity alone does not determine the ability of a rock or sediment to yield groundwater. Rock or sediment can be very porous and still not permit water to pass through it. Permeability is also very important.

Permeability

Permeability is the ability of a material such as rock, sediment, or soil to transmit water. It depends upon several factors, however, the most important is that the material must contain interconnected pore spaces. Generally, the more interconnections there are, the higher the permeability. The size of the pore spaces also affects permeability. Groundwater moves by flowing through the pathways provided by the pore spaces. The smaller the pore spaces, the more slowly the water moves (hence, the lower the permeability). If the spaces between particles are too small, the films of water clinging to the grains come into contact, and the force of molecular attraction extends across the pore space, resulting in no water movement. Clay is very porous, but the pore spaces are so small that molecular attraction holds the water in place so that it is unable to move. Sand and gravel, being composed of larger particles and having larger pore spaces, are considerably more permeable than clay. In these materials the water in the center of the pore spaces is not bound by molecular attraction and can move relatively easily. In rocks having little or no interconnected pore spaces, fracturing becomes important as a means of providing porosity and permeability.

Fracture Porosity and Permeability

Fracture porosity and permeability originate in response to unloading of overlying bedrock or to regional tectonism. When erosion removes overlying rock, the release in pressure permits the underlying rocks to expand, fracturing them.

Fractures, joints, and bedding-plane partings are expressions of pressure release when bedrock undergoes stress. Bedding planes can be weak points that separate, forming horizontal partings or fractures. In Figure 4, note that the bedrock near the surface (upper 1000 feet) resembles a stack of variously sized blocks that fit together very closely. Fractures very near the surface tend to be wider than those at greater depths. These joints or fractures may extend vertically or horizontally for considerable distances. The interconnecting fractures provide secondary porosity and permeability in bedrock that has low primary porosity and permeability.

In limestone, fracture porosity is enhanced by solution of the bedrock along fractures and bedding-plane partings, resulting in conduits of considerable diameter and extent (Figure 5). Slightly acidic groundwater initially entering bedding planes and newly formed fractures dissolves the limestone along these openings. Over time, as more water moves through the openings, they are further enlarged. Openings in some limestones are large enough to allow people to walk through them. These openings are known as caves. Since joints usually intersect other joints and/or bedding plane fractures, solution along these features eventually results in greatly increased permeability as the conduits and their interconnections are enlarged. (Figures 4 and 5).

Water movement through solution-enlarged conduits is often similar to surface stream flow. If the conduits are large enough, water may flow turbulently and rapidly through them, often measured in rates as high as several miles per hour. In mature karst terrain, the conduit systems are well developed, and the potential for rapid underground flow makes this type of region highly vulnerable to contamination from spills or leaks of a hazardous material. Once in the conduit system, a contaminant can move rapidly, often affecting water wells and springs in the surrounding area before emergency measures can be emplaced.

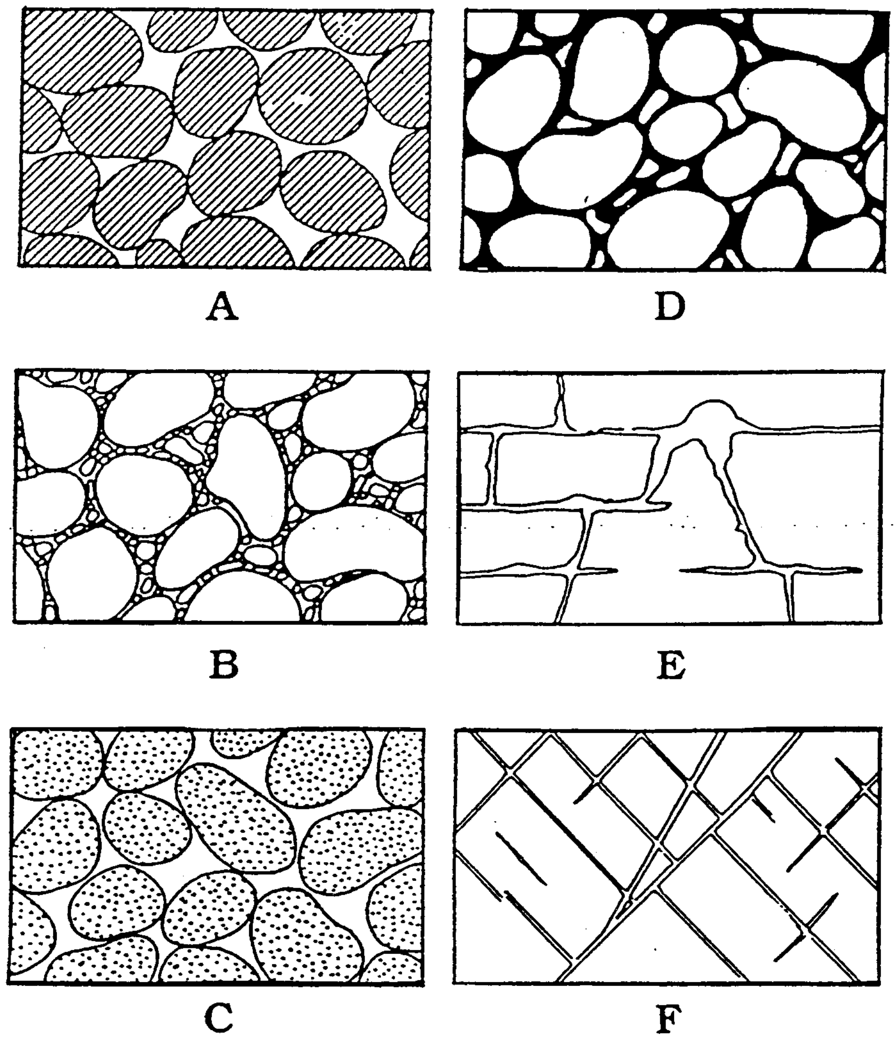

Figure 3. Types of Pore Spaces and the Relationship of Rock Texture to Porosity. (A) Well-sorted sediments having high primary porosity; (B) poorly sorted sediments having low primary porosity; (C) well-sorted, porous sedimentary grains with open pore spaces; (D) well-sorted sedimentary deposit having diminished porosity due to deposition of cement in pore spaces; (E) rock having secondary porosity due to solution; (F) rock having secondary porosity due to fractures (modified after O. E. Meinzer, 1923).

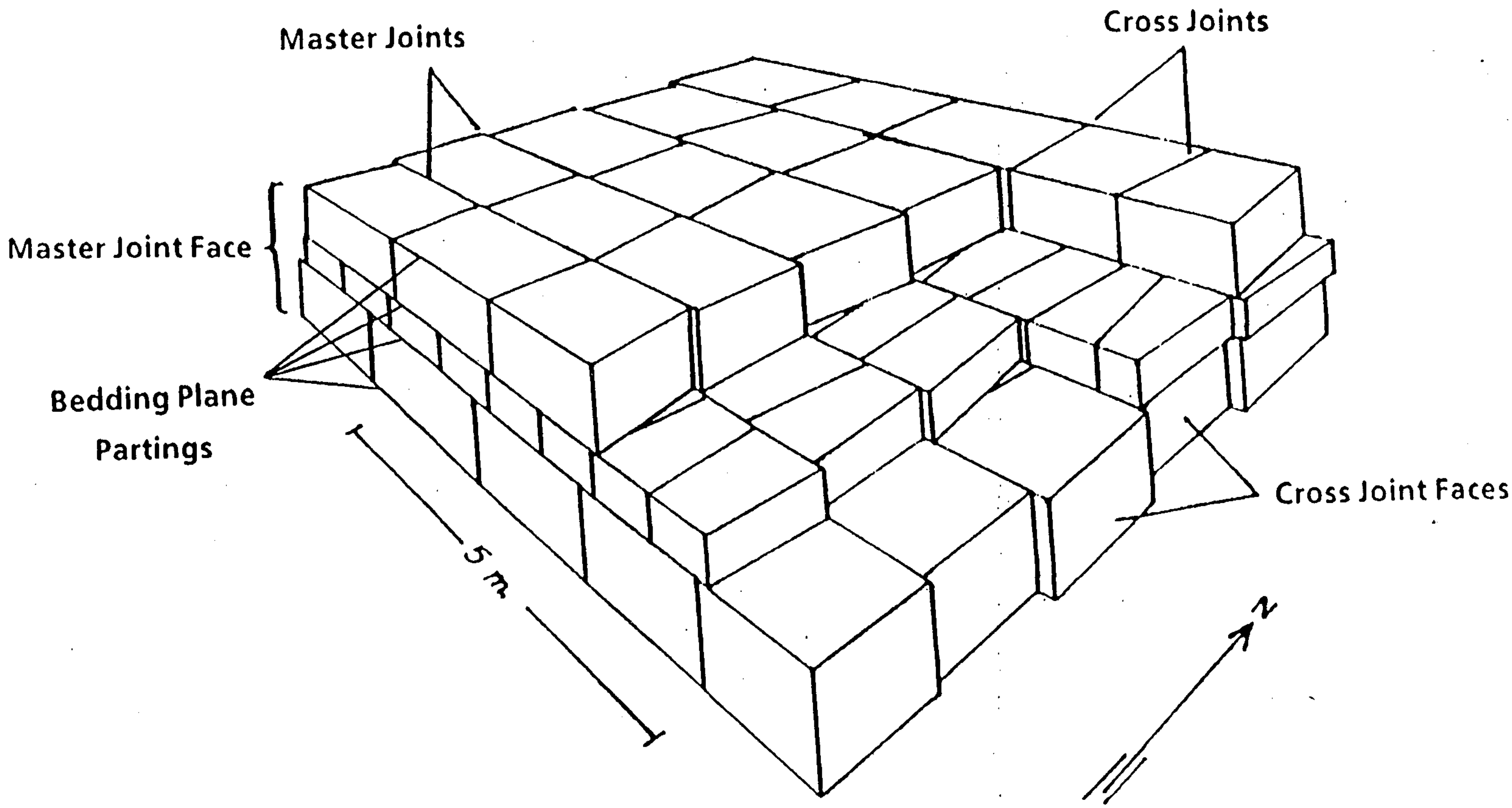

Figure 4. Block Diagram Illustrating Common Fracture Patterns in Limestone Bedrock (modified after Powell, 1977).

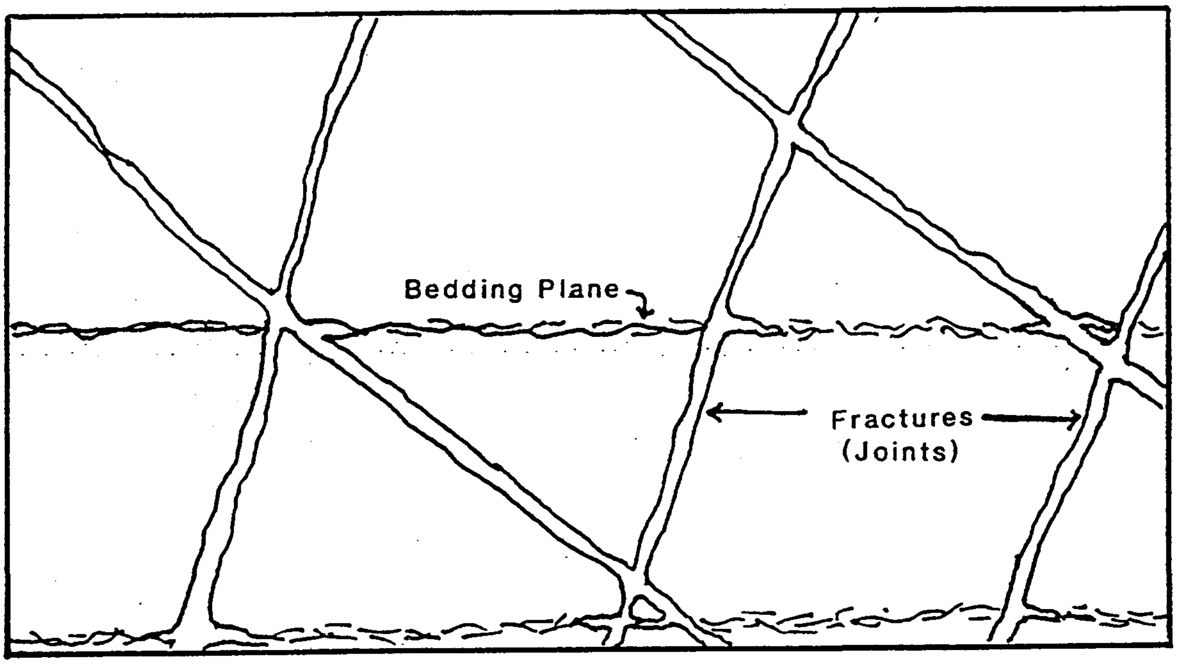

Figure 5. Interconnected Fractures and Bedding Planes in Limestones. Such fractures provide secondary permeability to the rock mass, allowing groundwater to flow through them (modified after Smith and others, 1982).

AQUIFERS

Aquifers are permeable rock units that are capable of storing and transmitting groundwater. Good aquifers include unconsolidated sands and gravels, well-jointed sandstones, limestones, and dolomites. Aquifers may be confined or unconfined, depending upon their physical surroundings.

Unconfined Aquifers

An unconfined aquifer has no overlying impermeable layer that restricts the vertical movement of water. Instead, continuous layers of high permeability material extend from the land surface to an impermeable layer that marks the base of the aquifer. Within this area the groundwater is distributed into several distinct zones (Figure 2). Rainfall that infiltrates the land surface first enters the soil moisture zone. A portion of the percolating water moves farther downward through the unsaturated zone in which the pore spaces are partially filled with water. Water then moves into the saturated zone, where the pore spaces are completely filled with water. The saturated zone defines the extent (thickness) of the unconfined aquifer. Further downward circulation of water may be prevented by the presence of an impermeable rock layer.

The boundary between the unsaturated zone and saturated zone is the surface of the water table. The water level in a well intercepting an unconfined aquifer marks the top of the water table. The position of the water table does not remain at a constant elevation, but it rises and falls in response to changes in volume of water in storage in the aquifer. This storage changes seasonally and in response to groundwater discharge (Figure 6). The water rises in seasons of the year during which recharge is heavy and falls in drier months. Also, the water table drops if more groundwater is pumped out of the ground (discharged) than is replaced through recharge. Recharge in an unconfined aquifer is not only from downward seepage through the unsaturated zone, but also through lateral groundwater flow or upward seepage from underlying permeable layers. The shape of the water table approximately follows the overlying topography. In Figure 8, note that the water table is highest in elevation under hills and lower in the valleys.

Confined Aquifers

Confined Aquifers are bound above and below by impermeable rock or sediment layers which may be called confining beds (Figure 7). Water enters a confined aquifer in the recharge area where the aquifer crops out on the land surface, or through interconnection with another aquifer. Generally, the water pressure at almost any point in a confined aquifer is greater than atmospheric pressure. Changes in water levels within wells that penetrate a confined aquifer are primarily the result of changes in pressure due to fluctuations in the recharge volume, or in the volume of water being discharged. Barometric pressure (pressure of the atmosphere) changes may also significantly affect water levels in wells that penetrate a confined aquifer.

If a tightly cased well is drilled into a confined aquifer, the water, under pressure, may rise to a considerable distance above the top of the aquifer. The actual height to which the water will rise in the well is called the potentiometric surface. It is an imaginary surface that coincides with the hydrostatic pressure level (hydrostatic head) of the water in the aquifer. The water level in the well defines the elevation of the potentiometric surface at

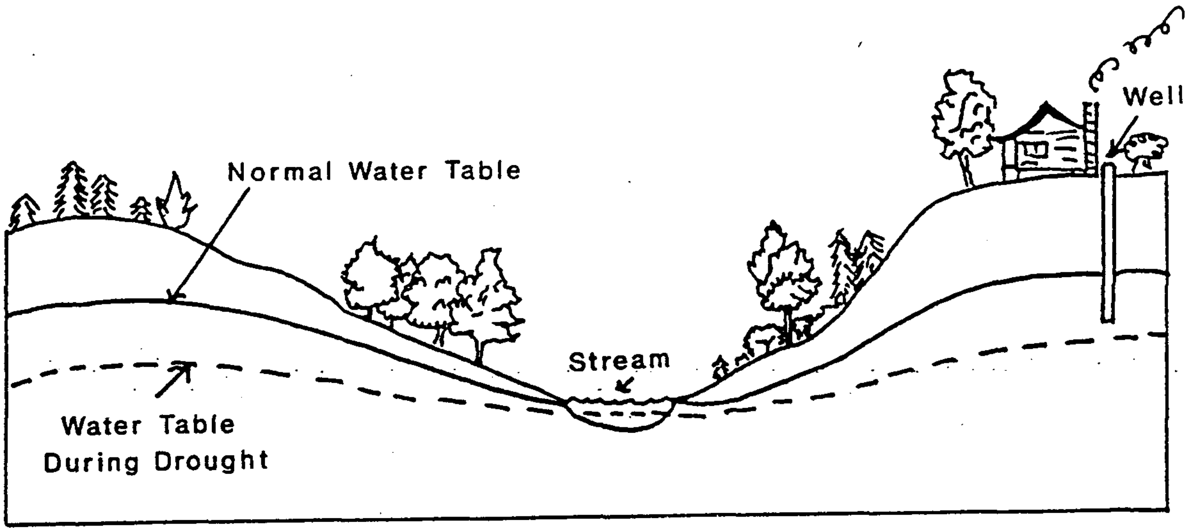

Figure 6. Hypothetical Sketch of the Seasonal Shape of the Water Table. The shape of the water table generally follows surface topography. During dry periods the water table falls, reducing stream flow and drying up some wells (modified after Tarbuck and Lutgens, 1984).

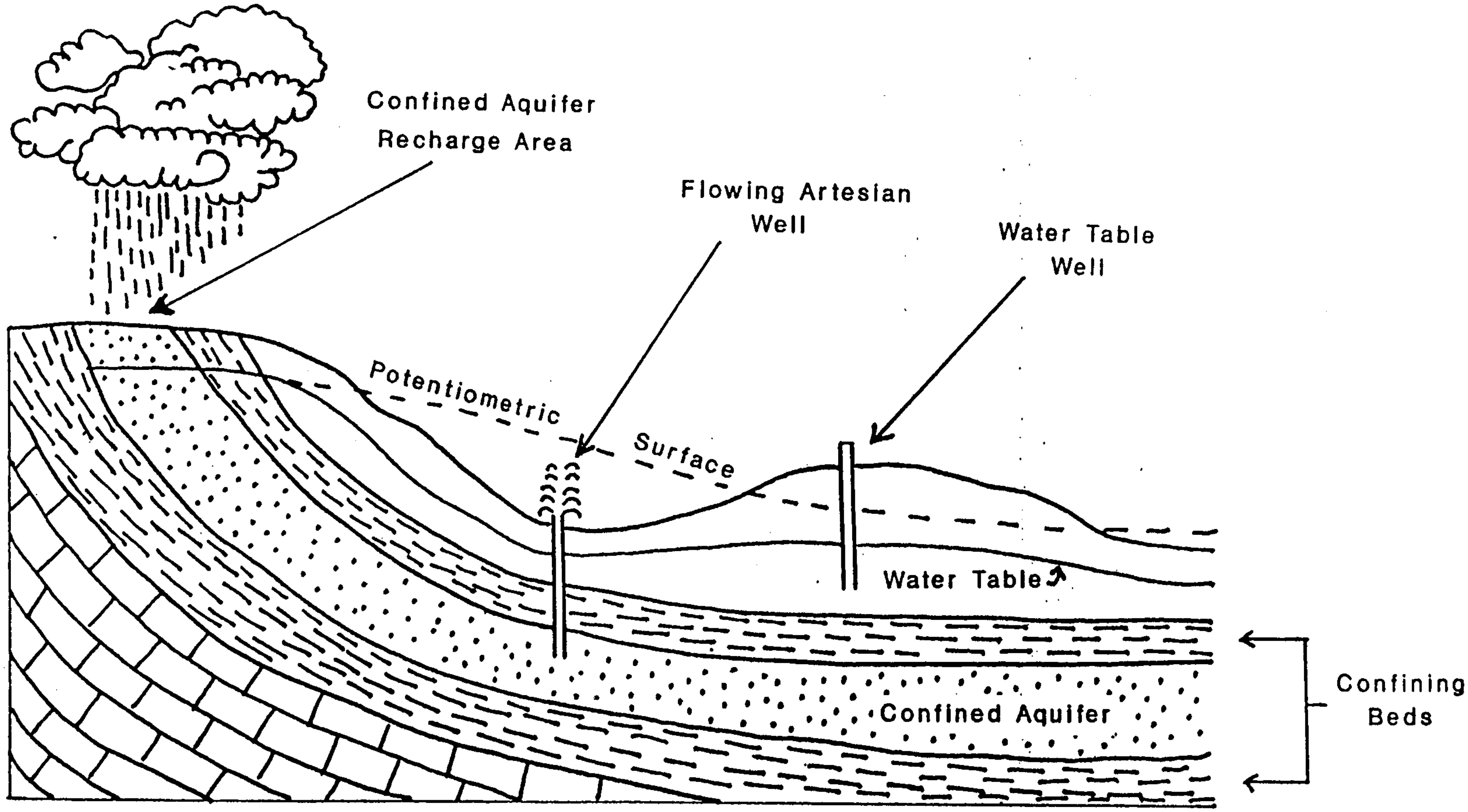

Figure 7. Geologic Section showing Confined and Unconfined Aquifers (modified after Tarbuck and Lutgens, 1984). See text for explanation.

that point. If the potentiometric surface lies above the ground surface, a flowing artesian well results (Figure 7).

The potentiometric surface of a confined aquifer is analogous to the water table of an unconfined aquifer, but it is not the same because the potentiometric surface is an imaginary surface; the water table is not.

GROUNDWATER FLOW THROUGH AQUIFERS

The nature of groundwater flow through an aquifer is determined by the permeability of the rock or sediment. For example, pore spaces in a silty, fine sand are quite small and water molecules move very slowly through them in essentially parallel flowlines (laminar flow). On the other hand, water may flow very rapidly and turbulently through solution-enlarged fractures, joints, and conduits.

Groundwater moves from areas of high to low elevation or pressure. The magnitude and direction of change in groundwater elevations or pressures is called a gradient. In most aquifers, the gradient can be determined by measuring the static water levels of wells penetrating the aquifer, plotting these measurements on a map, and determining the direction and amount of decline in the elevation of water levels. In karst areas however, water level elevations measured in wells may provide misleading information about the regional groundwater flow gradient. This is partially due to the fact that the gradient in a karst aquifer is often controlled by the orientation and slope of solution conduits and fractures. Wells may penetrate different sections of the conduit network, providing conflicting information. Also, constrictions in the sizes (diameters) of conduits and fracture openings can result in localized increases in pressure within an aquifer. If wells penetrate a zone of increased pressure, the higher elevations of the recorded water levels may be incorrectly interpreted with regard to the gradient of the regional flow in the aquifer.

Springs

Springs are formed in locations where groundwater discharges at the surface. There is a wide variety of spring types due to the wide variation in subsurface conditions from one area to another. The quality of spring water varies directly with the water quality in the aquifer and the recharge feeding the spring. Characteristics of karst springs are discussed in a following section of this report.

Granular Aquifers

Many karst areas are overlain by <u>alluvial</u> <u>deposits</u> and soils which act as granular aquifers. Granular aquifers are composed of unconsolidated gravels, sands, silts, clays, and porous rock. Groundwater flow through this type of aquifer is laminar at a rate that ranges from as low as inches per year to several feet per day. Springs fed by granular aquifers generally have excellent water quality. The slow movement of water provides ample opportunity for removal of biological (bacteria and viruses) and other contaminants by prolonged contact with soil and rock particles. Water from other types of shallow aquifers is less likely to be as high in quality as that from a granular aquifer due to lack of opportunity for adequate purification.

Fracture-flow Aquifers

Fracture-flow aquifers exhibit secondary porosity and permeability due to the presence of fractures, joints, and bedding-plane partings. Groundwater flow in this type of aquifer ranges from laminar to <u>turbulent</u>. Turbulent flow occurs in fractures that are large enough in diameter to allow water to move rapidly and erratically through them. Where the directions and widths of fractures are varied and random, groundwater flow may be non-uniform, and aquifer characteristics may vary greatly from one point to another.

Carbonate Aquifers

In approximately 50 percent of Kentucky, limestone and dolomite are exposed at or underlie the surface (Fig 8). Because calcium carbonate is their primary chemical constituent, these rocks are collectively known as "carbonates". Most carbonate rocks in Kentucky are highly permeable as a result of extensive fracturing and are excellent groundwater reservoirs. Carbonate aquifers occur where these rocks are saturated with groundwater and yield significant supplies of water to wells or discharge water to springs.

Carbonate aquifers share many of the same characteristics as fracture-flow aquifers, with one important distinction: carbonates are soluble rocks. Groundwater movement through carbonate aquifers actively enlarges and modifies fractures and open pore spaces by solution. Therefore, over time, considerable changes occur in the subsurface conduit system of a carbonate aquifer which will affect the direction of groundwater flow, the rate and volume of water discharged through the aquifer and its conduits, and the location and characteristics of recharge zones and discharge zones. Obviously, these factors will have a direct impact on the quantity and quality of water issuing from a karst spring, and on the longevity of the spring itself.

In carbonate aquifers there are two types of flow systems which provide water to springs. In a <u>conduit flow system</u>, groundwater flows rapidly and turbulently through well-integrated, solution-enlarged conduits. There is a minimum contact with the soil horizon and aquifer media, hence, minimum opportunity for filtration. For this reason, water quality of conduit flow springs is similar to that of surface streams and may even be worse. Well-

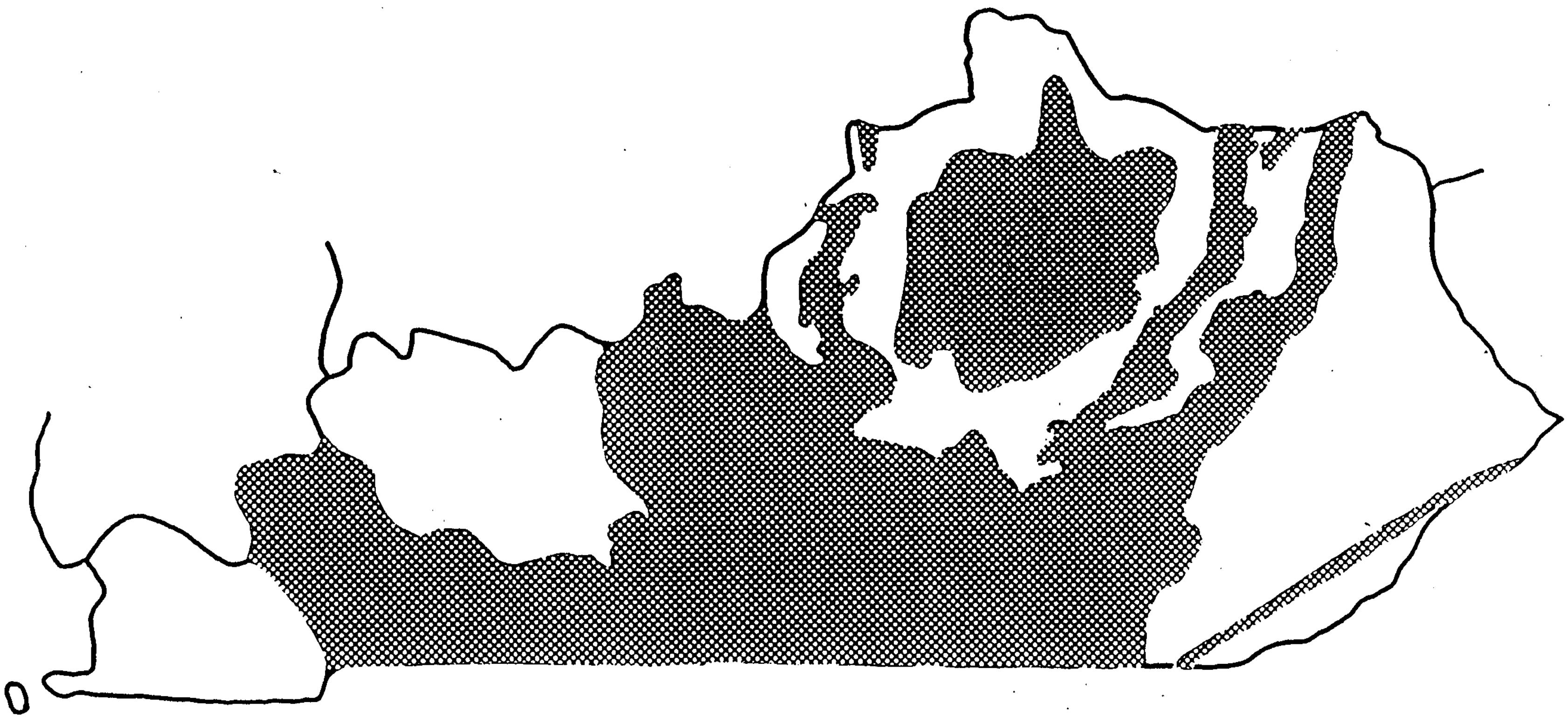

Figure 8. Areas of Potential Karst Groundwater Flow in Kentucky. Patterned areas indicate potential karst groundwater flow.

developed conduit systems are found in many areas of Kentucky, and especially in the Mammoth Cave region.

Diffuse flow systems occur in carbonates having a network of fractures and solution openings which, overall, behave like the pore spaces of granular aquifers. Generally, these fractures and solutional openings are very densely spaced and not well-developed or greatly enlarged. Groundwater flow is essentially laminar with sufficient opportunity for filtration through the soil horizon and fractures in the limestone. Water quality of diffuse flow springs is similar to that of granular aquifers. Most carbonate aquifers exhibit some characteristics of both conduit and diffuse flow.

Karst Springs

In Kentucky, karst springs issue from fractures or solution-enlarged openings in limestones or dolomite. There are several types of karst springs. Gravity springs flow from open cave mouths or fractures without any significant hydrostatic head. Blue hole springs appear to be pools from which water upwells from a conduit opening below the level of the surface. Seeps are diffuse, slow discharges of groundwater through rock or soil. The water quality of karst springs ranges from very good to poor, depending upon the quality of water entering the subsurface flow system.

Karst Topography and Hydrology

Landscapes underlain by gently dipping, jointed or fractured carbonate bedrock evolve as karst terrains by chemical and physical solution of calcite and dolomite. Groundwater moving through limestone is unique in that it has the capability to dissolve the limestone. Pure water cannot dissolve limestone, but slightly acidic water can. Rain absorbs some carbon dioxide as it falls through the atmosphere and is slightly acidic when it hits the ground. The water absorbs additional amounts of carbon dioxide as it infiltrates the soil horizon. Carbon dioxide is a major component of soil gas that originates from decaying organic matter and respiration of soil organisms. When water absorbs carbon dioxide, it becomes a weak carbonic acid solution which slowly dissolves the limestone bedrock as it infiltrates through fractures and bedding-plane partings. Dissolution of the limestone bedrock over time results in the development of landforms which characterize karst terrain. Karst topography is characterized by springs, sinkholes, sinking streams, caves, and well-integrated subsurface drainage networks (conduits) (Figure 9.). Where these landforms are abundant and well-developed, the karst terrain is termed "mature". Where these landforms are less abundant or are almost lacking entirely, the karst is termed "immature".

Mature karst terrains are characterized by well-integrated, extensive subsurface drainage systems. Surface stream drainage is generally disrupted or absent. Recharge areas to springs are often extensive, covering many square miles. Sinkholes, and other karstic landforms, are abundant and well-developed in such areas.

Surface water basins are controlled by topography. Karst groundwater basins are controlled by the subsurface drainage system connecting recharge areas to springs. Generally, subsurface karst basins do not coincide exactly with surface basins. Thus, a sinkhole in one surface stream basin can feed a spring or springs in a surface basin on the other side of the hill (drainage divide). Underground conduit systems may divide into many springs, or they may connect into a single conduit feeding a single spring.

Unlike surface water drainage basins, karst groundwater basins may vary in size and shape according to groundwater levels. During periods of low water

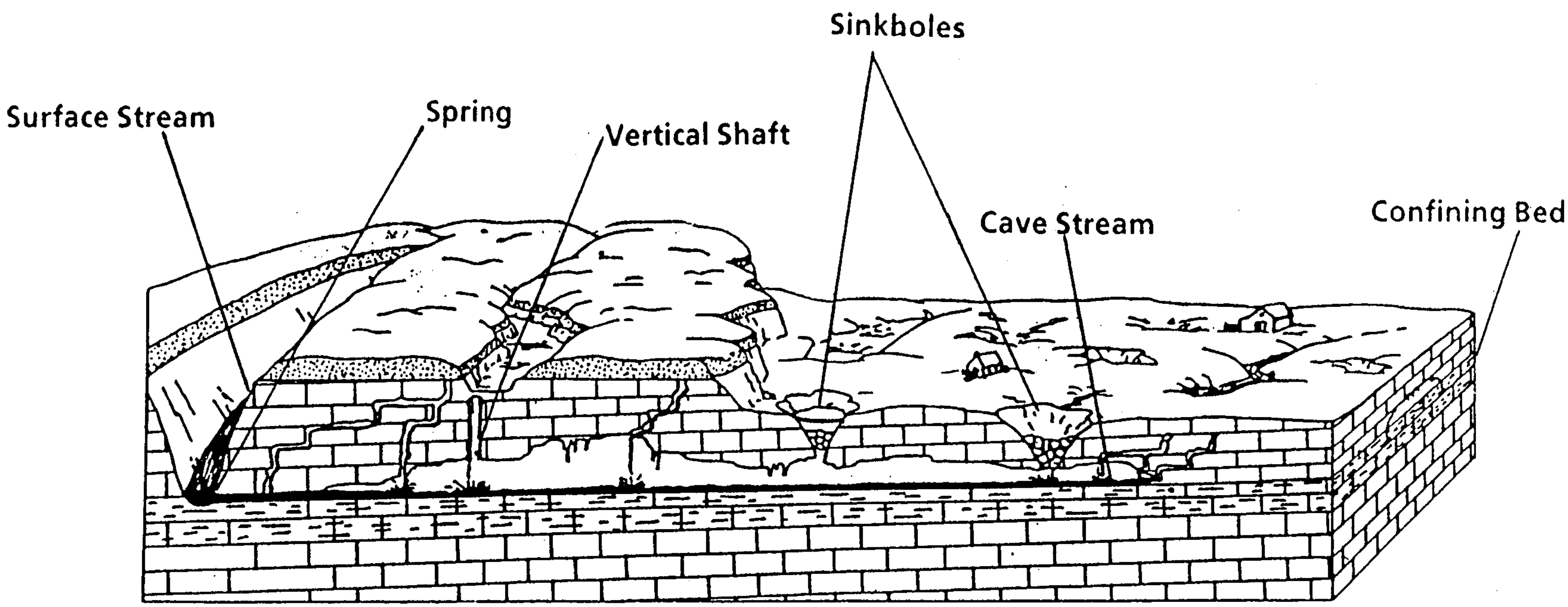

Figure 9. Block Diagram showing Surface and Subsurface Karst Features (modified after Currens and McGrain, 1979).

levels (low flow), basin flow may be to a single spring, with some conduits remaining dry. But during high flow, rising water levels may flood the dry conduits, and water from two or more normally separate karst basins joins through these high-level overflow routes.

The groundwater scientist who must predict the direction and flow rate of a contaminant in a karst aquifer has a challenging task because he/she must take into consideration whether the aquifer is primarily a diffuse flow or a conduit flow system, as well as the complexity of the conduit system. One helpful study that provides information on basin boundaries, flow directions, and flow rates is a dye-tracing study.

Groundwater Tracing

Dye-tracing is one type of groundwater tracing method that is used to determine the connections between recharge points (e.g. sinkholes and sinking streams) and discharge points (springs) in a karst groundwater basin. A non-toxic dye such as fluorescein is introduced into a sinkhole or sinking stream. Prior to dumping the dye, bugs (dye detectors) are placed in all suspected resurgences (springs). A positive dye-trace is obtained when the dye is absorbed by bugs in one or more springs. This confirms the existence of a subsurface connection between the sinkpoint that received the dye and the spring(s) in which the dye was detected.

The recharge areas and groundwater basin boundaries of karst springs can be defined through comprehensive, systematic, dye-tracing investigations. Many such studies have been conducted throughout the Commonwealth. Dye-tracing has been used to define and characterize the groundwater basins of springs which supply municipal water to the cities of Elizabethtown (Hardin County), Georgetown (Scott County), and Livingston (Rockcastle County). A number of individual groundwater basins supplying large karst springs have been identified by dye-tracing in the Inner Bluegrass Region (Thrailkill and others, 1982). The results of extensive dye-tracing conducted in the area enclosing Mammoth Cave National Park have delineated the entire subsurface drainage network and demonstrated the potential threat that local sewage and industrial waste discharges pose to the cave system and groundwater regime.

Little is known about the recharge areas of many springs currently being used as public or semi-public water supplies. Having information on file about the groundwater basins supplying these springs is vital in light of the nature of groundwater flow in karst terrain. A leak or spill of a hazardous material can quickly become a very serious problem since groundwater flow rates in karst aquifers are very fast (1300 feet per hour in some karst areas of Kentucky), and there is little or no filtration or attenuation of contaminants. Studies delineating karst groundwater basins can provide emergency response personnel with the necessary information to quickly predict where contaminants may migrate and estimate their arrival time once they have entered the conduit system.

CONTAMINATION THREATS TO GROUNDWATER IN KARST TERRAIN

Contaminants are potentially harmful substances introduced into the water as a result of improper disposal or accidental spillage of hazardous chemicals, waste materials and liquids. Filtration by soils, adsorption onto mineral grains and clay particles, dilution, and naturally-occurring breakdown of contaminants may prevent detrimental impacts to groundwater. However, the opportunity for some of these processes to occur is limited in karst areas due to presence of thin soils and the rapid movement of water directly through subsurface conduits. Like surface waters, karst waters are highly vulnerable to contamination. Every effort must be made to identify current or potential sources of contamination and take measures to control or eliminate them.

Sinkhole Dumps

Sinkholes traditionally have been used as dump sites for waste. Sinkholes generally represent land that cannot be developed. Many people believe that they are useless except as convenient sites for trash disposal. Farmers frequently use sinkholes to dispose of manure and carcasses of dead animals. Sinkholes are commonly filled with garbage, pesticides, fertilizers, and the proverbial junk household appliances and automobiles. Municipalities sometimes use sinkholes as landfills or dumps. Oil drilling operations have disposed of brines down sinkholes.

Attempts to explain the relationship between sinkholes, groundwater and springs either have been poorly understood or have fallen on deaf ears. Many people fail to recognize that the drains of sinkholes connect directly with subsurface conduit systems and provide direct, quick recharge to karst groundwater. Solid waste, much of which is hazardous, either falls into or is washed into the conduits where it corrodes or decays, providing a long-term source of contamination (Figure 10). Liquid wastes, including hazardous chemicals and sewage, seep or flow directly into groundwater upon disposal in sinkholes.

In rural areas having sparse populations, sinkhole dumps may cause problems that are undetected. In areas where the population density is greater, sinkhole dumps pose a serious contamination threat to those utilizing wells and springs as water supplies. For example, in 1970, the Smiths Grove (Warren County) water supply well was contaminated following the dumping of several truckloads of whey from a local creamery into a sinkhole.

Sanitary Landfills

Municipal trash in a sanitary landfill decomposes slowly in an oxygen-poor environment, producing a leachate that is a serious potential contamination threat to groundwater. To provide the greatest possible barrier to leachate transport, landfills should be located on thick soils, well above the water table, with good liners, leachate collection systems, and leachate treatment. Thin soils, sinkholes, and subsurface conduits make karst terrain one of the worst possible sites for landfills. The uneven support provided by the highly irregular bedrock surface in karst terrain can cause parts of the landfill to settle, causing the liners to crack. A normally designed landfill should not be sited in karst with shallow conduit systems, as they may transport leachate directly to springs or surface streams, contaminating them and preventing their use as public water supplies. Landfill development in karst areas requires careful site investigation, planning, and construction in order to minimize any detrimental impacts to groundwater.

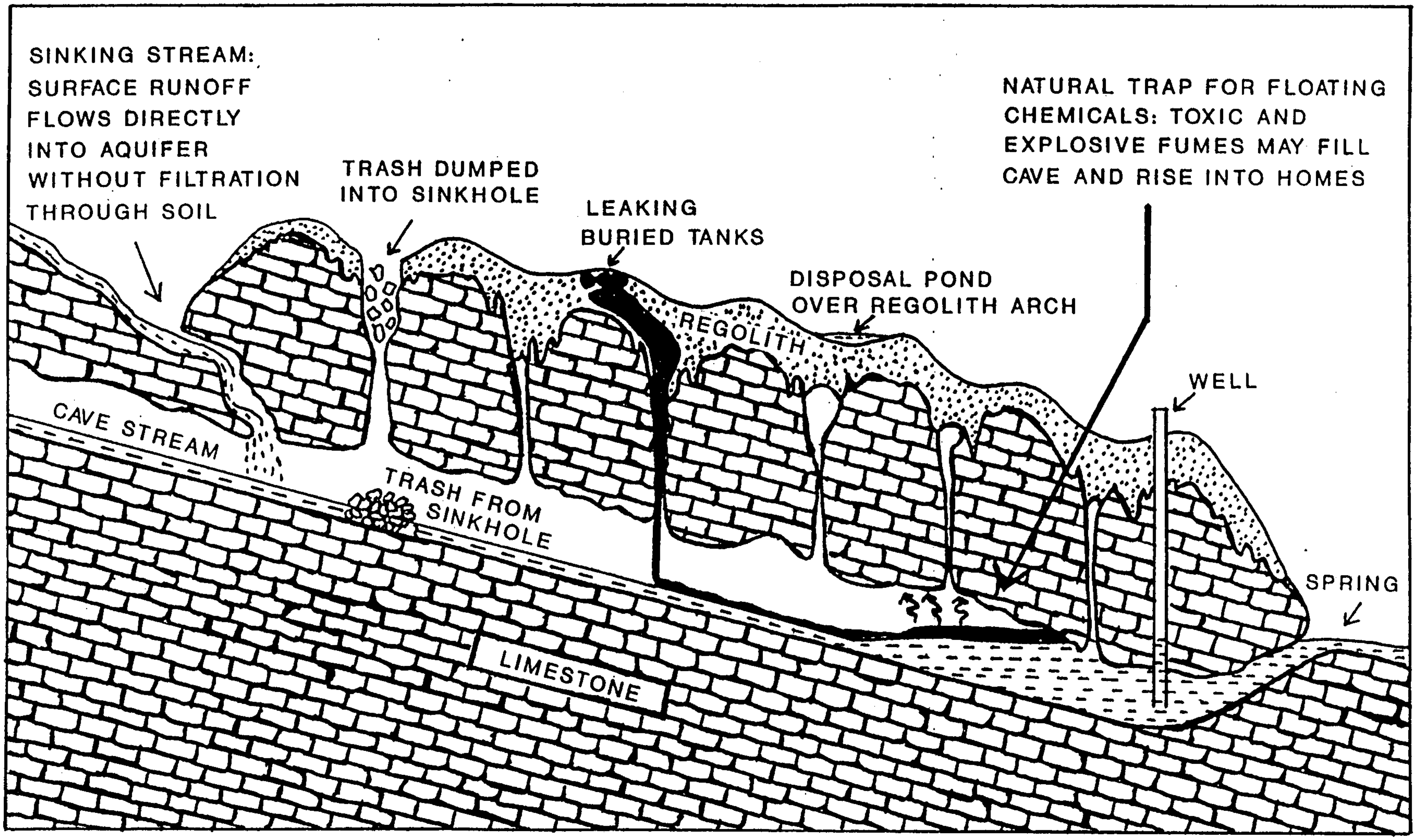

Figure 10. Sources of Contamination of Karst Groundwater (Crawford, 1988).

Septic Systems and Leaky Sewer Lines

Groundwater contamination from septic systems is common in karst areas. To function properly, leachfields (lateral lines) require several feet of porous, slightly permeable soil to promote slow drainage of septic tank effluent to provide adequate time for bacterial breakdown of the waste material and evaporation of liquids. Thin, clayey soils in karst regions may not be adequate, as septic tank effluent may drain quickly through these soils and into conduits in the limestone bedrock. A septic system failure such as this would go virtually undetected under most circumstances. In 1982, Meade County experienced a hepatitis outbreak that involved 120 cases of hepatitis, with one death. The outbreak was traced to septic tank effluent flowing to a nearby spring used as a public water source. Lexington was built around many springs that provided an abundant supply of clean water. As the city grew, the springs became contaminated with sewage after rains. Cholera epidemics occurred, killing hundreds of people in 1833 and 1849.

Some residents of karst regions run their sewer line directly into a sinkhole. The groundwater conduits draining the sinkhole become running sewers. This practice will result in widespread contamination of wells and springs in the area.

New types of septic systems or a regional sewage treatment system will help to prevent groundwater pollution. For example, Wisconsin is using mound-type septic systems in karst areas to prevent septic-system failure and groundwater contamination. In Kentucky, the Cabinet for Human Resources conducts on-site evaluations before granting permits for new septic systems. Old or improperly functioning septic systems, however, still pose a health threat to unprotected water supplies. Persons who are planning to build a home or upgrade a septic system may obtain helpful information from the Kentucky On-site Sewage Treatment Systems Technical Manual. This publication discusses a variety of on-site systems, new treatment techniques, and leachfield designs that may be adapted to a wide range of site conditions.

Contamination problems due to septic systems are not immediately solved by installing collection lines and a sewage treatment plant. Buildup or pooling of sewage effluent in subsurface conduits can continue to release contaminants into groundwater for prolonged periods of time. Even sewer lines can be a potential source of groundwater contamination. Pipelines laid in karst terrain may crack or separate when underlying support is removed through soil piping, which is the washout of soil in the subsurface by runoff water moving turbulently along channelized pathways toward a solution opening in the underlying bedrock. A cavity forms in the soil into which the pipe may sag or collapse, spilling sewage into the surrounding soil or fractures in the subsurface bedrock. The use of a new flexible piping with heat-fused connections may prevent future groundwater contamination in areas where soil piping is a problem.

Due to the lack of large surface streams in karst areas, effluent from sewage treatment plants may be discharged into sinkholes, sinking streams, or losing streams. Although less hazardous than untreated effluent, treated wastewater is still not a desirable additive to groundwater. Wastewater receives limited treatment at the sewage treatment plant, because it is assumed that the stream receiving the effluent will provide the final cleansing. Sunlight, aeration, and biodegradation are expected to remove the remaining pollutants. Unfortunately, most of these cleansing factors are absent in the subsurface conduits. Consequently, incompletely treated effluent still may readily contaminate nearby springs and wells. The state of Kentucky controls discharges of treated wastewater to sinkholes through the KPDES permitting program.

Dry Wells (Drainage Wells, Class V Injection Wells)

Drainage wells (dry wells) are common in Kentucky's urban karst areas and provide a direct route for surface water to enter a karst aquifer. Gasoline, oil, lead, and other contaminants associated with urban runoff are directly injected into the aquifer. Technically, these wells are Class V injection wells as defined by the United States Environmental Protection Agency (USEPA) and must be registered with the EPA within one year after construction. Currently, the EPA is developing more stringent regulations governing drainage wells. These regulations may make future use of drainage wells less attractive. Kentucky state laws prohibit the discharge of untreated sewage or industrial waste into a dry well or sinkhole.

Feedlot and Barnyard Runoff

Large amounts of organic wastes are produced by dairy herds, beef, cattle, horse, pig and poultry farms. The leachates from manure piles contain decomposing organic matter, phosphorus, several forms of nitrogen (ammonia, ammonium, nitrogen, nitrite, and nitrate), and fecal coliform bacteria. These contaminants become part of the surface-water runoff from the feedlots and barnyards.

Although several forms of nitrogen are initially present in the leachate, only the nitrate is a potential problem in groundwater. As the leachate moves through the soil, chemical reactions change the ammonia and nitrites to nitrate by the time they reach the groundwater. The fecal coliform bacteria excreted in the manure die off shortly after leaving the gut of the animal, but they can persist for some distances while being transported in the groundwater.

Runoff from feedlots and barnyards can contaminate groundwater by entering the subsurface conduit system through sinkholes and sinking streams. From studies conducted in karst terrain near State College, Pennsylvania, Kastrinos and White (1986) pinpointed agricultural runoff into sinkholes as the main source of elevated nitrate levels in springs. They found a direct correlation between nitrate levels in springs and the agricultural use of the land in the groundwater basin feeding the springs.

The high nitrate levels and presence of fecal coliform bacteria in groundwater used for domestic purposes pose serious health risks. Water high in nitrate is life-threatening to infants that are fed formula prepared from such water. High nitrate levels (greater than 45 mg/L nitrate or 10 mg/L nitrate-nitrogen) have been known to cause infant methemoglobinemia, a condition characterized by a bluish tint to the skin. (National Academy of Sciences, Drinking Water and Health, 1977, p. 437). Infants suffering from this potentially fatal condition require immediate medical attention. Fecal coliform bacteria generally do not cause disease. However, they are indicators of direct pollution by animal or human feces and the possible presence of disease-causing micro-organisms (bacteria and viruses) in the water.

Composting, processing, and selling animal manure as fertilizer has become a profitable second income for increasing numbers of farmers. Composting not only provides additional income, but also solves a solid waste disposal problem.

THE INTERRELATIONSHIP BETWEEN GROUNDWATER AND SURFACE WATER

Many people believe that groundwater contamination problems can be "written off" once private and public water supplies are obtaining water from a surface water supply. These people fail to realize that groundwater provides the base flow of most rivers and streams. Therefore, contaminated groundwater contributes to contaminated surface water. This is especially true in karst areas where springs form the headwaters of surface streams or contribute significant quantities of water to surface streams.

On the other hand, surface streams often lose portions of their flow to groundwater through swallets (drain-like openings), fractures, or bed seepage in the stream channel. Sinking streams are surface streams which have all of their flow diverted underground into subsurface conduits. In these situations, the contamination of surface water can result directly in the contamination of groundwater.

GLOSSARY

ACIDIC - a generally corrosive, water-soluble compound which is capable of reacting with a base to form a salt. An acid solution has a pH less than 7 (neutral).

ALLUVIAL DEPOSITS (Alluvium) - Clay, silt, sand, gravel, or other unconsolidated sediments deposited by a stream or other body of running water.

AQUIFER - a permeable rock unit capable of storing and transmitting groundwater in usable quantities.

ARTESIAN WELL - a well in which the water rises to the surface under its own pressure, without being pumped.

ATTENUATION - natural properties or processes in a groundwater system which act to inhibit the movement of a contaminant.

BASE FLOW - water that sustains a river throughout dry weather.

BASE LEVEL - the level or elevation at which a stream loses its energy and can no longer cut downward into its bed.

BED - a layer of sedimentary rock more than 1 centimeter thick; also the bottom of a stream channel.

BEDDING PLANE - a nearly flat surface separating 2 beds of sedimentary rock.

BEDDING PLANE PARTING - a fracture or surface of separation between adjacent beds of rock.

BEDROCK - a general term for the rock, usually solid, that underlies soil or other unconsolidated material.

BLUE HOLE SPRING - a spring whose waters appear to upwell from a pool below the level of the surface.

BUG - a dye detector placed in the water to determine whether or not the dye has passed that particular location.

CALCITE - a rock-forming mineral, $CaCO_3$ (calcium carbonate); main constituent of limestone.

CARBONATE BEDROCK - limestone or dolomite bedrock.

CEMENT - mineralized infilling, usually chemically precipitated in spaces between grains of sediments, binding them together to form solid rock.

CONDUIT - a passage formed in bedrock through solution by groundwater. The passage may or may not be filled with water.

CONDUIT FLOW SYSTEM - groundwater flows rapidly and turbulently through well-integrated, solution-enlarged subsurface conduits.

CONFINED AQUIFER - an aquifer bounded above and below by impermeable layers, or by beds of distinctly lower permeability than that of the aquifer itself.

CONFINING BED - a geologic unit (rock or sediment) that has little or no permeability, effectively inhibiting groundwater flow across it.

CONTAMINANT - potentially harmful substance introduced into the water as a result of improper disposal or accidental spillage of hazardous chemicals, waste materials and liquids.

CROPS OUT- exposed at the surface of the ground.

CRUST - outermost layer of the earth.

DIFFUSE FLOW - a flow pattern that tends to spread out as it flows through a porous medium.

DIFFUSE FLOW SYSTEM - groundwater flows through numerous poorly-developed fractures and bedding-plane partings in the bedrock. Flow is essentially laminar.

DISAPPEARING STREAM - a surface stream that disappears underground in a karst region through a fracture, swallet, or sinkhole. See also: Sinking Stream.

DOLOMITE - a sedimentary rock composed of the mineral dolomite, $CaMg(CO_3)_2$ (calcium magnesium carbonate).

DRAINAGE DIVIDE - a ridge or strip of high ground that separates one surface water drainage basin from another.

DRAINAGE WELL - a well used to inject soil water or surface water, where the penetrated aquifer is permeable enough and has a head far enough below the land surface to drain the water at a satisfactory rate: A USEPA Class V Injection Well: Dry Well.

DYE TRACE - a groundwater-tracing method used to determine groundwater flow paths. Dye is injected at an input point (sinkhole) and discharge points (springs) are monitored for appearance of the dye.

EROSION - the physical removal of rock by gravity, running water, or wind.

FAULTING - the formation of fractures in bedrock along which movement of the rock has taken place.

FILTRATION - the process of removing material from a liquid by passing it through a porous medium having small holes. The material too large to pass through the holes is filtered out.

FORMATION - a body of rock that has a recognizable unity or similarity (of color, texture, fossil content, or the like) that makes it distinguishable from adjacent rock units. A convenient unit for mapping, describing, or interpreting the geology of a region.

GRADIENT - The difference in elevation or slope of the water table over a given horizontal distance.

GRAVITY SPRINGS - springs that flow from open cave mouths or fractures without any significant hydrostatic head.

GROUNDWATER - that part of subsurface water found in the zone of saturation.

GROUNDWATER BASIN - a large, natural groundwater reservoir that receives recharge from surface and/or subsurface drainage basins and has fairly distinct boundaries, recharge areas and discharge points.

GROUNDWATER TRACING - a means by which groundwater flow routes may be determined. A tracer substance is added to streams at swallow holes, cave streams, or flushed down sinkholes by heavy rainstorms or by tank trucks of water. Tracers are then picked up by detectors at discharge points (springs). Tracers that may be used include dyes, spores, salt, microorganisms, rare elements, and radioactive substances.

HEAD - the elevation to which water rises at a given point as a result of reservoir pressure.

HYDROLOGY - the study of water. It includes the occurrence, distribution, movement, and chemistry of all waters of the earth.

HYDRAULIC CONDITIONS - conditions or forces that influence the flow of water.

HYDROSTATIC HEAD - the height of a vertical column of water, whose weight is equal to the hydrostatic pressure at a given point in the aquifer.

HYDROSTATIC PRESSURE - the pressure exerted by water at any given point in a body of water at rest. The hydrostatic pressure of groundwater is usually due to the weight of water at higher levels in the Zone of Saturation.

JOINT - a fracture or crack in bedrock along which essentially no displacement has occurred.

KARST - a topographic terrain formed on limestone, dolomite, gypsum, and other rocks by solution. Karst topography is characterized by presence of sinkholes, caves springs, sinking streams, and a well-integrated subsurface drainage network.

KPDES - Kentucky Pollutant Discharge Elimination System. This program regulates discharges to surface streams. The allowable concentrations of contaminants in discharge waters are established based upon a stream's ability to carry contaminants in non-harmful concentrations.

LAMINAR FLOW - Water flow characterized by each molecule of water traveling a smooth, straight-line path parallel to neighboring molecules and the channel wall. The water molecules move downstream without mixing. Water flow through sand and small fractures is generally laminar. Contrast with turbulent flow.

LEACHATE - liquid derived from water percolating through buried refuse in sanitary landfills and dumps. Leachates contain large numbers of inorganic and organic contaminants, many of which are toxic.

LIMESTONE - a sedimentary rock composed of the mineral calcite, $CaCo_3$, (calcium carbonate).

LITHIFICATION - the process, of converting sediments to solid rock, generally by cementation and/or compaction.

LOSING STREAM - water flows from the stream to the aquifer. This can occur when a stream flows across permeable material and the stream bed is higher than the water table. It is possible for a river to be a gaining stream over one part of its length and a losing stream over another part; or for the same stretch to be a gaining stream at some times and a losing stream at others, as the water table rises and falls. A gaining stream receives water from the aquifer.

MOLECULAR ATTRACTION - the force that makes a thin film of water stick to a rock surface despite the force of gravity, which operates by the attraction of oppositely charged molecules.

PERMEABILITY - the ability of a material (rock, sediment, soil) to transmit water.

POROSITY - the percentage of the total volume of rock or sediment that consists of pore spaces.

POTENTIOMETRIC SURFACE - an imaginary surface representing the total head of groundwater and defined by the level to which water will rise in a tightly cased well. In a confined aquifer, the potentiometric surface is above the true, natural surface of the aquifer. Syn.: piezometric surface, pressure surface.

PRIMARY POROSITY - the original pore space between particles or grains of the rock. It is created by the geologic processes governing deposition of the sediment and forms before the sediment is lithified.

PUBLIC WATER SYSTEM (supply) - "any system owned by any person, for the ion to the public of piped water for human consumption, if such system has at least fifteen (15) service connections or regularly serves an average of at least twenty-five (25) individuals daily at least sixty (60) days of the year, and includes any collection, treatment, storage, or distribution facility under control of the operator of such system..." (401 KAR 6:015, Section 1).

RAW WATER SOURCE - a source of water that has not been filtered and treated by chlorination or other purification methods.

REGOLITH - the unconsolidated layer of soil, sediment and rock fragments that partially or completely covers bedrock.

RECHARGE - the addition of water to the aquifer by precipitation or by man-made holding ponds.

RESPIRATION - internal life processes that supply an organism's cells with oxygen needed for metabolism and relieves them of the carbon dioxide formed in energy-producing reactions.

RESURGENCE - the point where underground water appears at the surface.

SATURATED ZONE - a zone in which all pore spaces are filled with water under pressure greater than that of the atmosphere; separated from the unsaturated zone by the water table. SYN.: phreatic zone

SECONDARY POROSITY - porosity that forms after the sediment has lithified and occurs as fractures, joints, cracks, bedding-plane partings, and solution-enlarged conduits.

SEDIMENT - loose, solid particles that can originate by: (1) weathering and erosion of pre-existing rocks; (2) chemical precipitation from solution, usually in water; (3) secretion by organisms.

SEEPS - springs of extremely low discharge which appear as wetted surfaces or slow, trickling flows on rock surfaces or soils.

SEMI-PUBLIC WATER SUPPLY - "any water supply made available for drinking or domestic use which serves more than three (3) families but does not qualify as a public water system" (401 KAR 6:015, Section 1).

SINKHOLE - a naturally-occurring topographic depression in a karst area. Its drainage is subterranean and serves as a recharge point for the karst aquifer; formed by collapse of a conduit or the solution of bedrock below.

SINKING STREAM - a surface stream that disappears underground in a karst region usually through gradual seepage of flow along the channel bottom.

SOIL MOISTURE ZONE - the uppermost part of the unsaturated zone into which plant roots extend.

SOIL PIPING - the formation of a cavity in the subsurface due to removal of soil by turbulent flow of concentrated surface-water runoff, i.e., caves that form in soil.

SOLUTION - a process of chemical weathering by which mineral and rock are dissolved (ex.-calcium carbonate in limestone is removed by slightly acidic groundwater).

SOLUTION-ENLARGED CONDUITS - conduits formed by enlargement of fractures, joints, and bedding-plane partings. These structures are gradually widened as the limestone bedrock immediately adjacent to them is dissolved by slightly acidic groundwater.

SPRING - a place where groundwater flows naturally from rock or soil onto the land surface or into a body of water.

SUBLIMATION - a process by which a substance changes from a solid to a vapor without first being converted to a liquid.

SURFACE WATER DRAINAGE BASIN - the total land area that is drained by a stream.

SWALLET - an opening through which surface drainage disappears underground. Syn.: swallow hole, ponor

TECTONISM - movement of the earth's crust resulting in formation of ocean basins, continents, plateaus, and mountain ranges.

TERRAIN - a large piece of the earth's crust with a distinctive geological character (e.g. karst terrain)

TOPOGRAPHY - the shape of a land surface defined by its relief (changes from high elevations to low elevations).

TRANSPIRATION - a process by which water produced by the plant during photosynthesis is evaporated into the atmosphere from the plant surface.

TURBULENT FLOW - eddying, swirling flow in which water travels rapidly along erratically curved paths. Waterflow through wide fractures, caves, and surface streams is generally turbulent. Contrast with laminar flow.

UNCONFINED AQUIFER - an aquifer with a free water table which is at atmospheric pressure. The water is not confined above by relatively impermeable rocks.

UNCONSOLIDATED - a sediment that is loosely bound together, or whose particles are not cemented together.

UNSATURATED ZONE - a subsurface zone in which pore spaces are partially filled with water. Extends from land surface to the water table Syn.: Vadose Zone

WATER TABLE - the surface between the unsaturated zone and the saturated zone; the upper surface of an unconfined aquifer at which the pressure is equal to that of the atmosphere.

WEATHERING - the disintegration and erosion of the rock at or near the earth's surface brought about by exposure to the atmosphere (water, glacial ice, wind) and biosphere (plant roots, burrowing animals).

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